MODEL BASED SYSTEM ENGINEERING FOR SPACE ROBOTIC SYSTEMS

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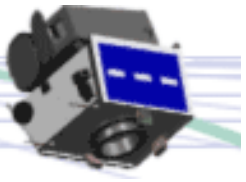

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- **Model based system engineering (MBSE) – SysML**
  - Tool Choice
- **SysML for INVERITAS**
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- **Conclusion and Future work**
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System Engineering

The success of the Space robotic missions heavily relies on the performance of many interconnected systems and systems of systems.

•Space robotic missions involves semi-autonomously or autonomously highly nonlinear Mechatronics systems

•In order to realise these missions, thorough analysis should commence right at the foundation level, i.e. at the 'systems' level.

- Mission requirements
- Accurate system modelling
- Effective communication between systems, systems of systems and the outside world are critical to the success of these missions

System Engineering

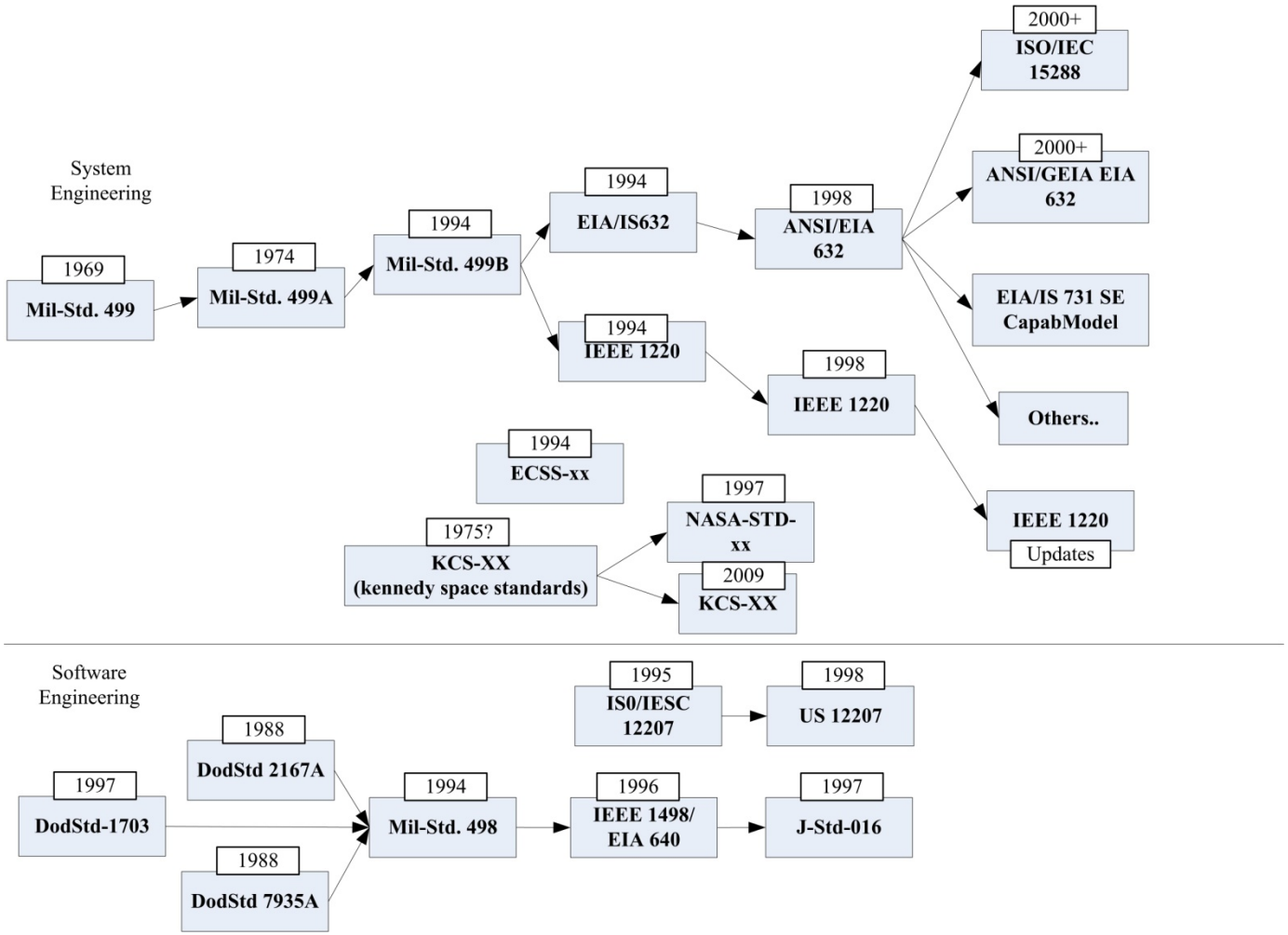


Figure 1 Heritage of system engineering standards [1]

System Engineering

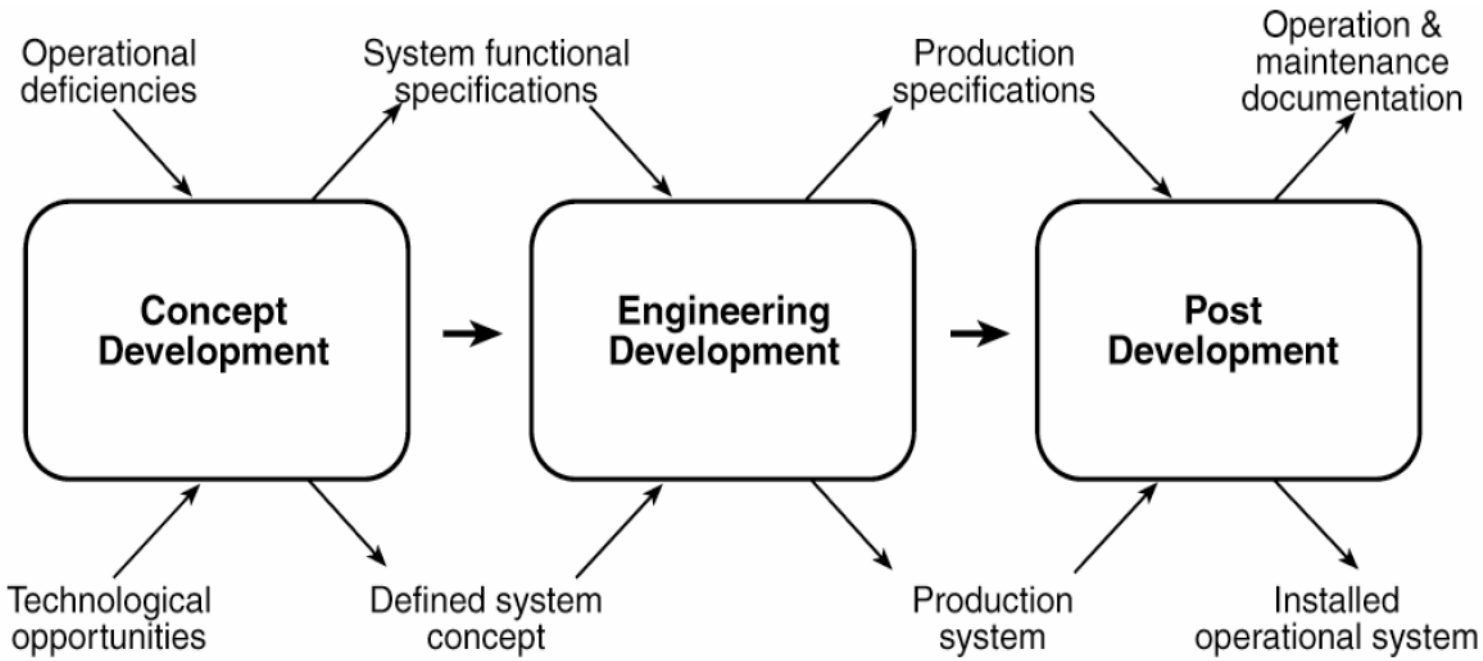


Figure 2 Principle phases of system engineering process life cycle [2]

MBSE : Model based SE

- Shift from document centric to model centric approach
- Model is a central artifact
- SysML : System Modeling language by OMG

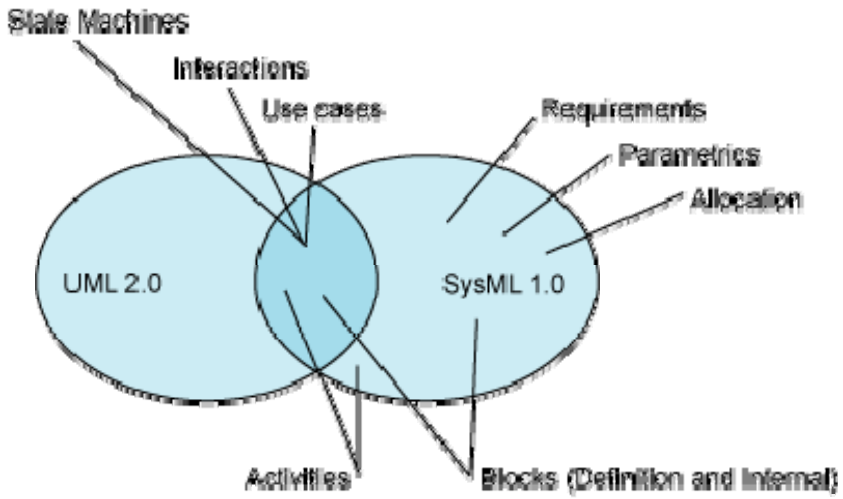


Figure 3 UML and SysML

- SysML is a subset of UML 2.0 with extensions.
- Share many diagrams with UML;
- Certain UML diagrams are renamed in SysML
- Has two new diagrams.

SysML : Introduction

Is a visual modelling language that provides

- Semantics = meaning
- Notation = representation of meaning

Is not a methodology or a tool

- Methodology and tool independent
- However, 'Rhapsody' or 'Enterprise Architect' are specific vendor tools that implement SysML (and UML)

➢SysML supports system specification, requirement engineering, analysis, design, verification and validation of systems that include

Hardware
Software
Data
Personnel
Procedures
Facilities

➢Supports model and data interchange via XML Metadata Interchange (XMI®) and the evolving AP233 standard (in-process)

SysML : Diagrams

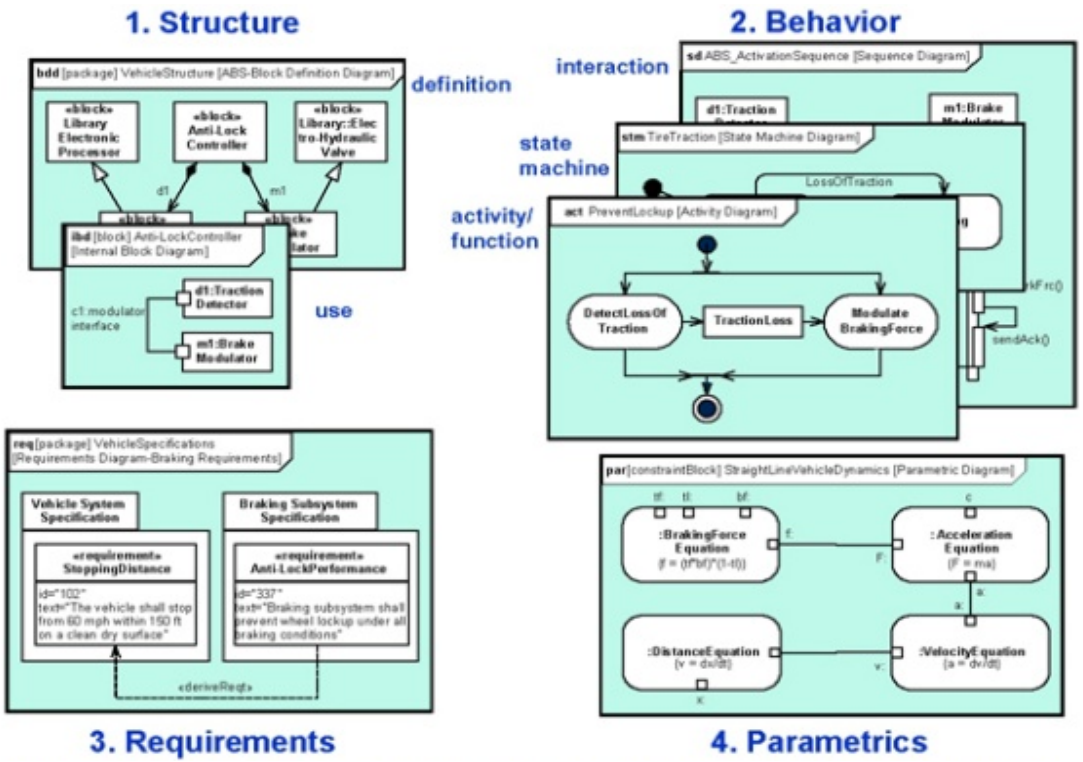


Figure 4 Four main pillars of the SysML (Source: OMG)

SysML : Tool choices

- IBM Rhapsody – A chosen tool

  - Supports language-independent and operating system–independent modelling.
  - Provides domain specific language support graphical C, MARTE or DoDAF, MODAF and UPDM add on.
  - Rhapsody has automated verification and validation capability.
  - Fully compatible with IBM Rational DOORS and other requirement management solutions.
  - Well established support and they have shown long term product development commitment.

Project : INVERITAS

INVERITAS

Innovative technologies for relative navigation and capture

•Co-funded by DLR & EADS Astrium
•Partners: DFKI, Jenaoptronik
•Application scenario : Satellite servicing
Lunar landing

Figure 5 DEOS space segment with the Client and Servicer spacecraft (source: STI, DLR [3])

Technology focus

- System Engineering
- Sensor data processing
- GNC for close rendezvous

SysML : Integrated SE lifecycle

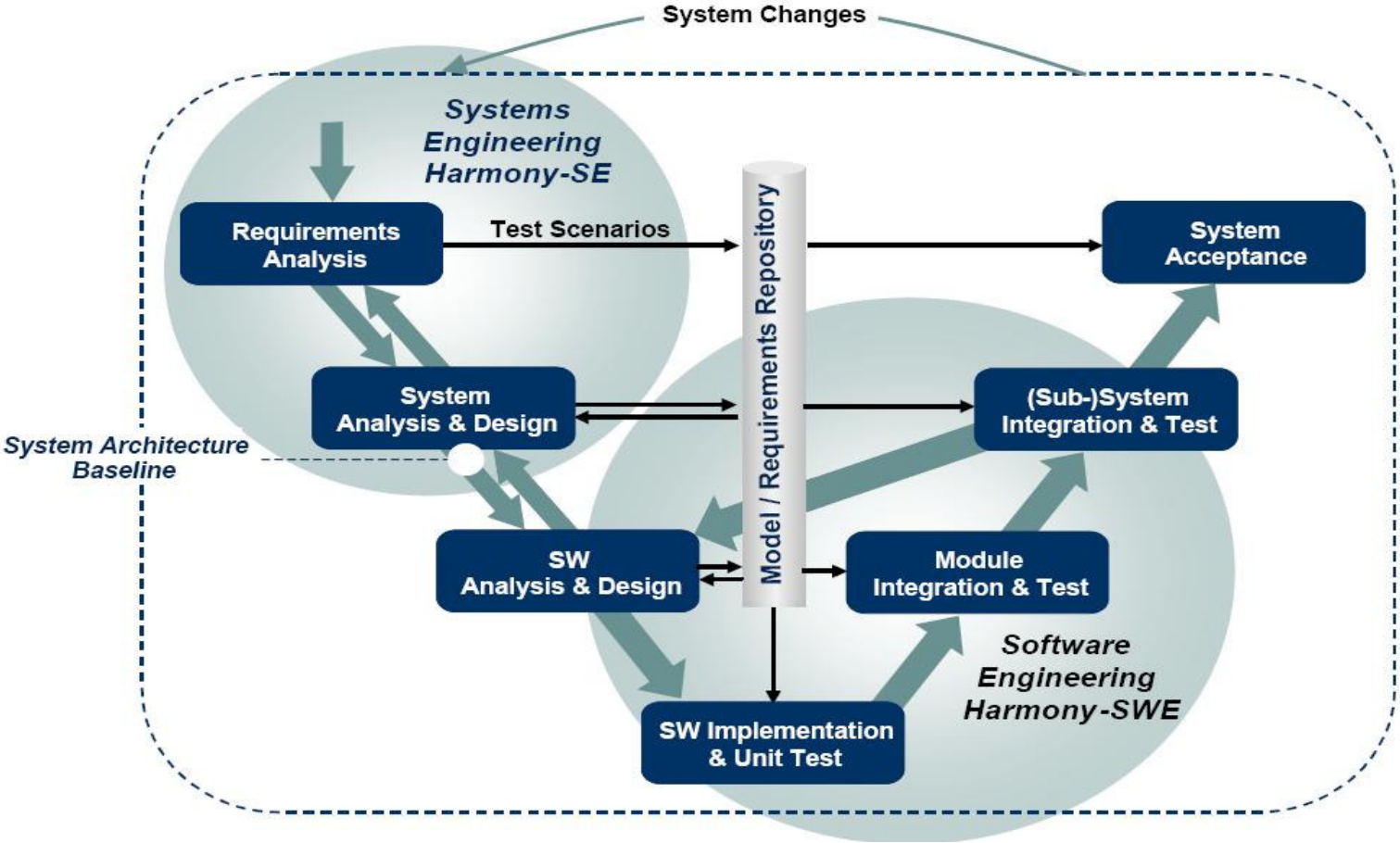


Figure 6 Integrated Systems and Software life cycle - Telelogic Rhapsody
(inspired from classical " Vee" model [4])

SysML-SEP Workflow

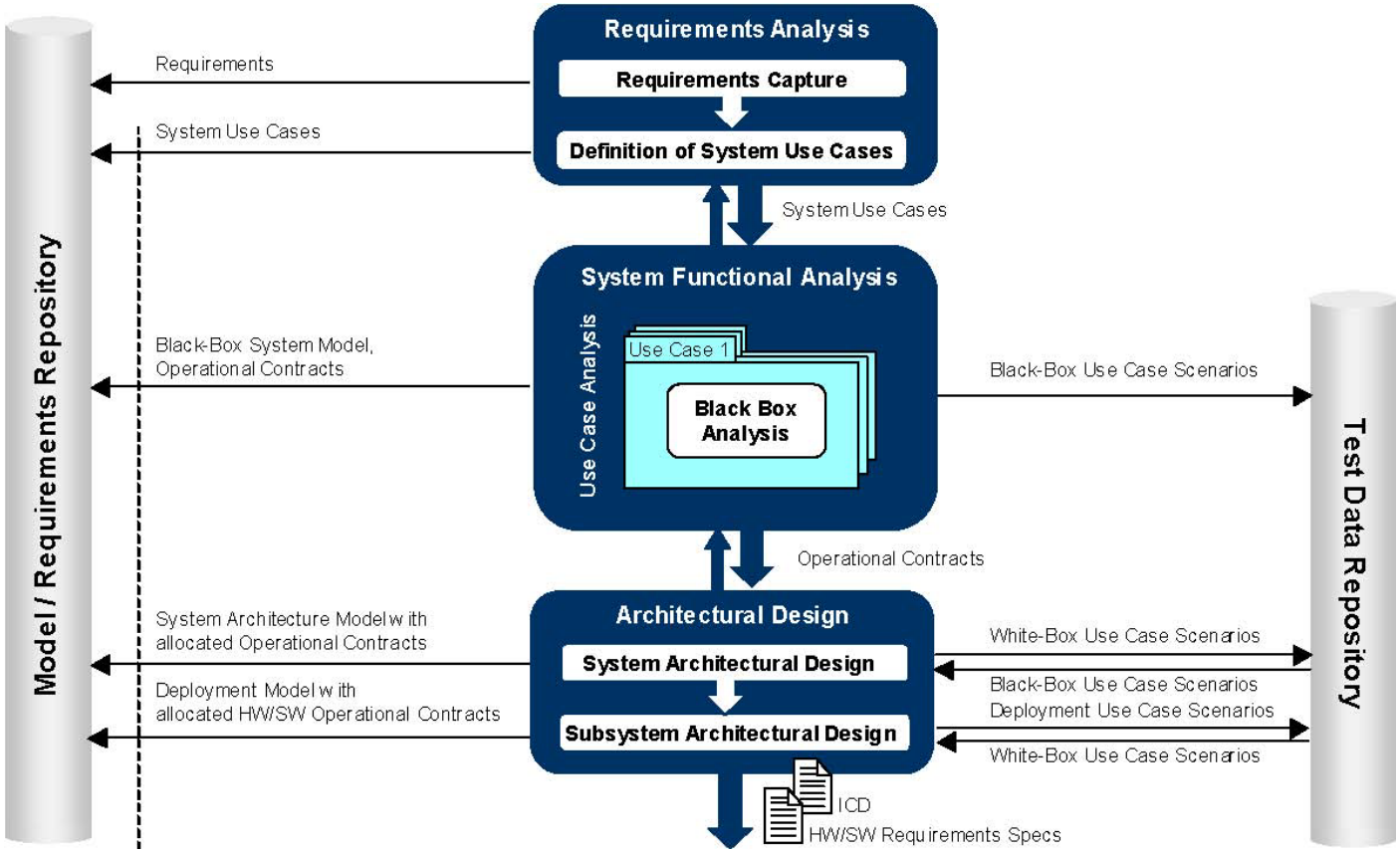


Figure 7 SysML based SE process [4]

SysML-SEP

- One of the advantages of SysML modelling is the inherent organisation and navigability that is possible through the explicit structure of the model.

Drawback

- SysML is not a formal language

Implication

- Our Study shows that two system engineers independently working on same system could come up with totally different SysML models.

- Requires developing robust and stringent in-house best practise and SysML guidelines.

Aim

- To develop modular and reusable SysML user profile and package structure for the INVERITAS project and for future complex space projects.

SysML profile

Aim of profile

➢Profile forms basis for standardised hierarchical system design and it will streamline the global model organisation and forms a System engineering process using SysML.

Strengths

➢Excellent **portability** for future projects and **modular packages**. This profile is also easily customisable to cater for specific need of a project.

➢Supports **different views** of model for different stakeholder needs and also provides facility to view black box/white box view.

➢It captures four main areas of a system: **Descriptions**, **Requirements, System Design** and **Sublevel**.

SysML profile

- Predefined stereotypes
- Naming rules
- Automated reports
- Version control
- Dynamic relations and links

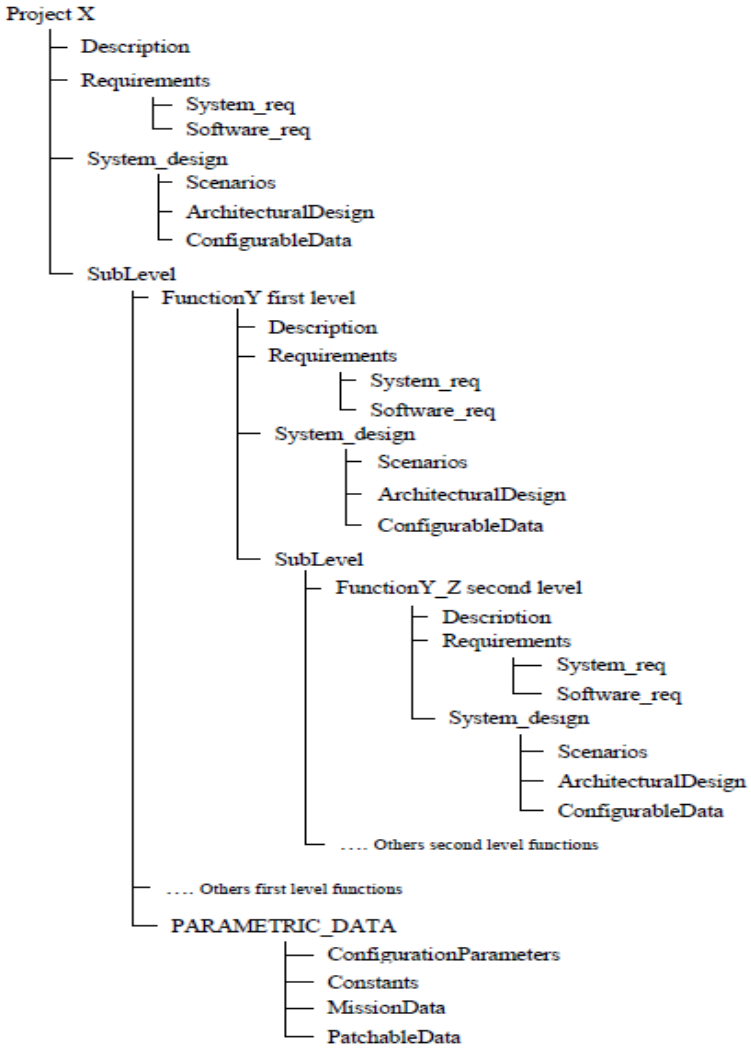


Figure 8 Proposed SysML packaged structure for complex Space robotic systems

INVERITAS: Multimodal Sensor Sys.

Multi-sensor approach

- A hybrid sensor system of multi-modality sensory input, data fusion, data exchange and representation.

- It results in unified perceptual experiences that are coherent across sensory modalities.

- Multi layered information which is in some sense better than would be possible when these sources were used individually.

- A smart hybrid sensing system identifies operating range and performance limitation of individual sensors and switches to most precise sensing solution for given range

INVERITAS : Multimodal Sensor Sys.

Integration of various 2D-/3D sensors

- LIDAR
- Far- and close range cameras
- Stereo cameras
- Gripper cameras

Sensor Fusion

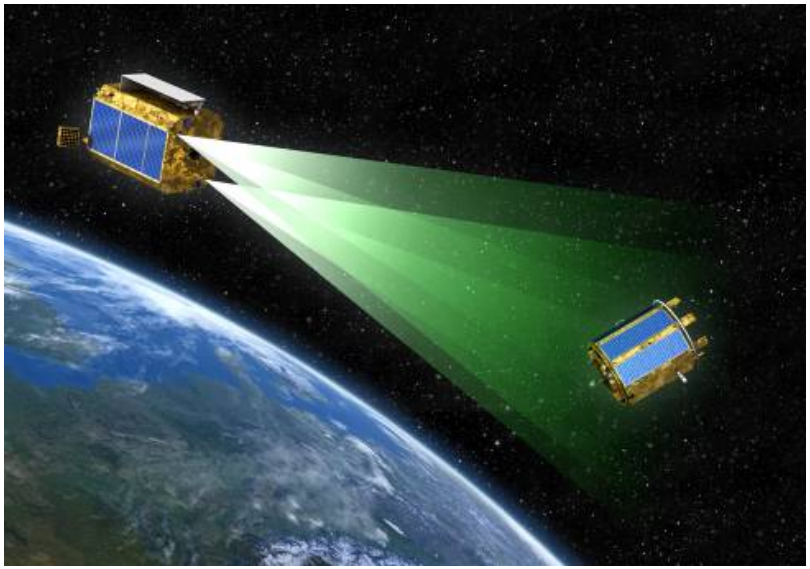
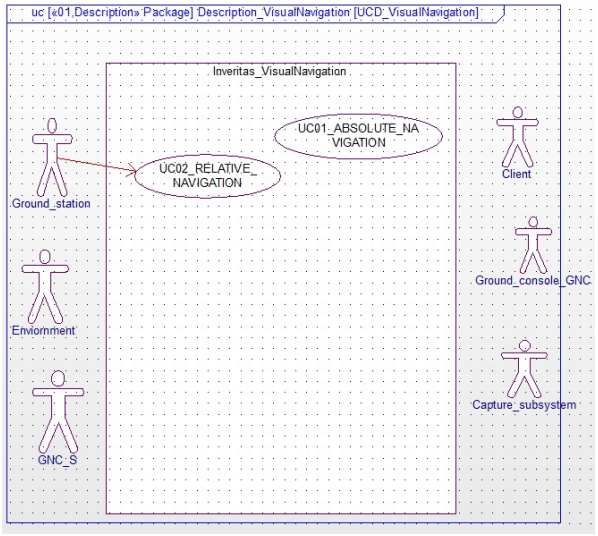
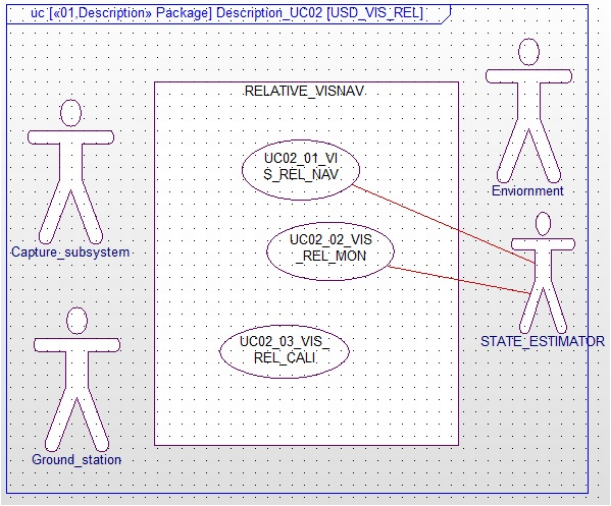


Figure 9 DEOS space segment with the Client and Servicer spacecraft (source: STI, DLR [3])

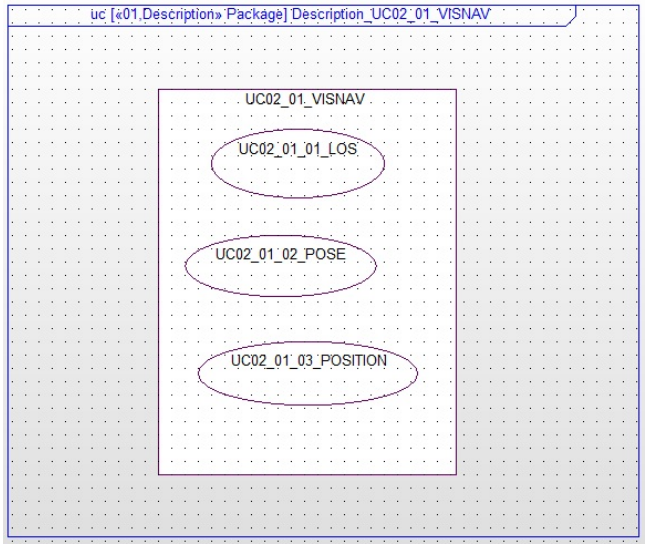
SysML : Rhapsody model



(a) First level
Use case and stake holders



(b) Second level
Use case and stake holders



(c) Use case – third level

Figure 10 High-level incomplete use case and identified stake holders

SysML : Rhapsody model

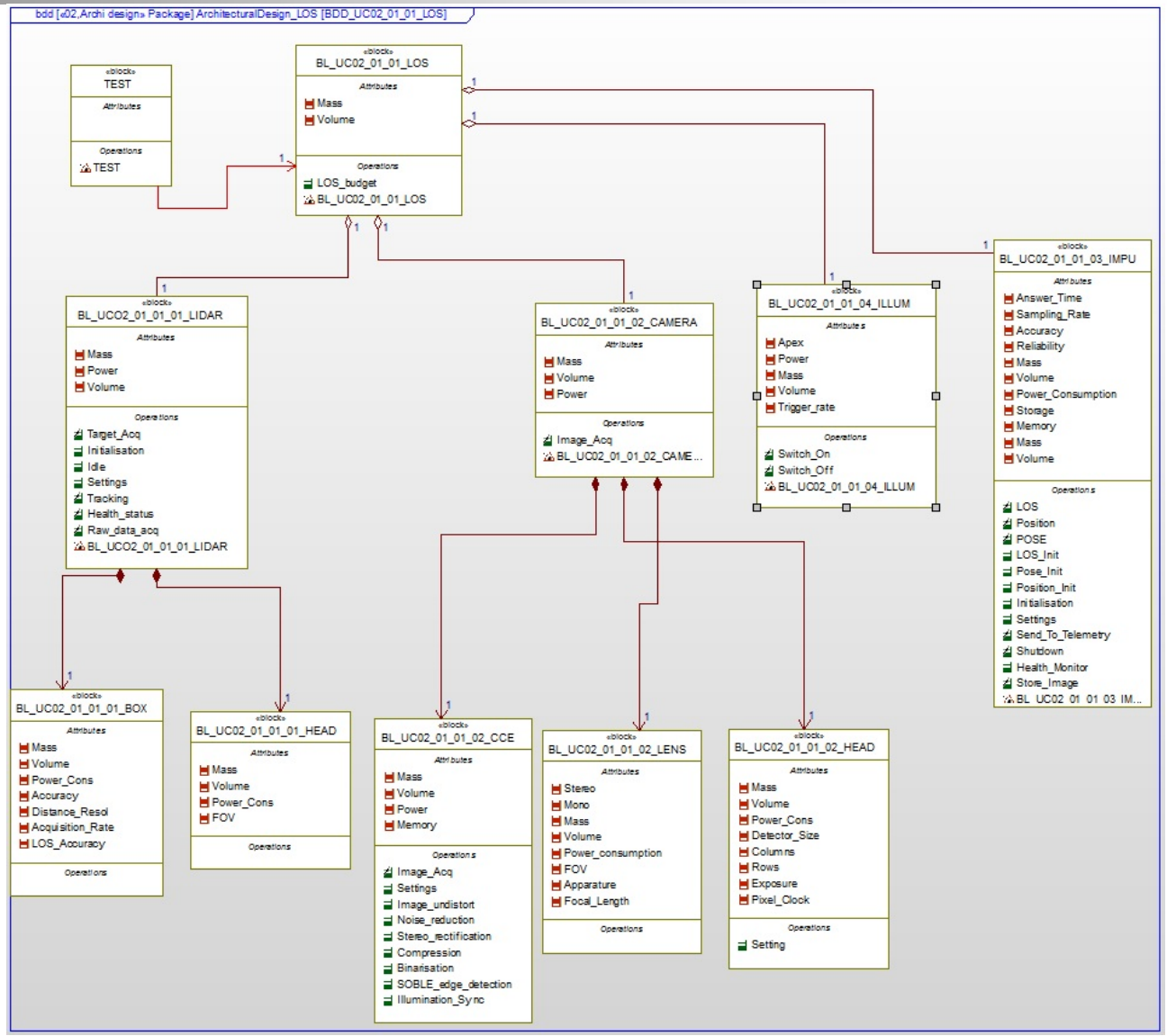


Figure 11 Architectural design UC02_01_01_LOS

Proposed Concept for Model Refinement

- Development of Use Cases would be helpful to identify further second level functions or refinement of those along with sublevel functions.
- Development of SysML Requirement Diagram to organise and capture all the requirements from very beginning for the INVERITAS "VisualFunctions".
- Discussion on Internal block diagrams to enable white box view of system.
- Identification of state diagrams and/or activity diagram.

Requirement Engineering (RE)

- Requirement for a system are a collection of needs expressed by stakeholders respecting some constraints under which the system must operate.

- Requirement engineering can include two main group of activities

  (i) **Requirement development**, including eliciting, documenting, analysing and validating requirements

  (i) **Requirement management**, including activities related to maintenance such as tracing and change management of requirements

- Classification of requirements based on level of detail :

  - **User requirements** : A high level abstract requirements based on end users and other stakeholders viewpoint.

  - **System requirements** : It is derived from user requirements but with detailed description of what the system should do.

SysML requirement verification

Requirement grouping

- Modeling requirements with SysML helps managing system complexity from early design stage
- Grouping of requirements can be achieved through SysML package/profile management as well as through requirement diagrams.
- This structure will be adapted to ECSS-E-ST-10-06C which is ECSS standard for technical requirements and specification [5].

SysML requirement verification

Types of requirement relationships

- **Derive** : Relationships for defining requirements. Represents derived from its source
- **Satisfy** : It represents dependency relationship between a requirement an a model element.
- **Verify** : How a test case can verify a requirement. This includes standard verification methods for inspection, analysis, demonstration or test. For example, given a requirement, the steps necessary for its verification can be summarized by a state-machine diagram.
- **Refine**: Describes how a model element or elements can be used to later refine a requirement.

SysML requirement verification

- **Trace :** General purpose relationship between requirement and any model element.
- **Copy** : The hierarchy is built based on master and slave requirements. The slave is a requirement whose text property is a read-only copy of the master.

SysML requirement verification

- SysML requirement diagram helps in better organising requirements and also shows explicitly the various kinds of relationships between different requirements.

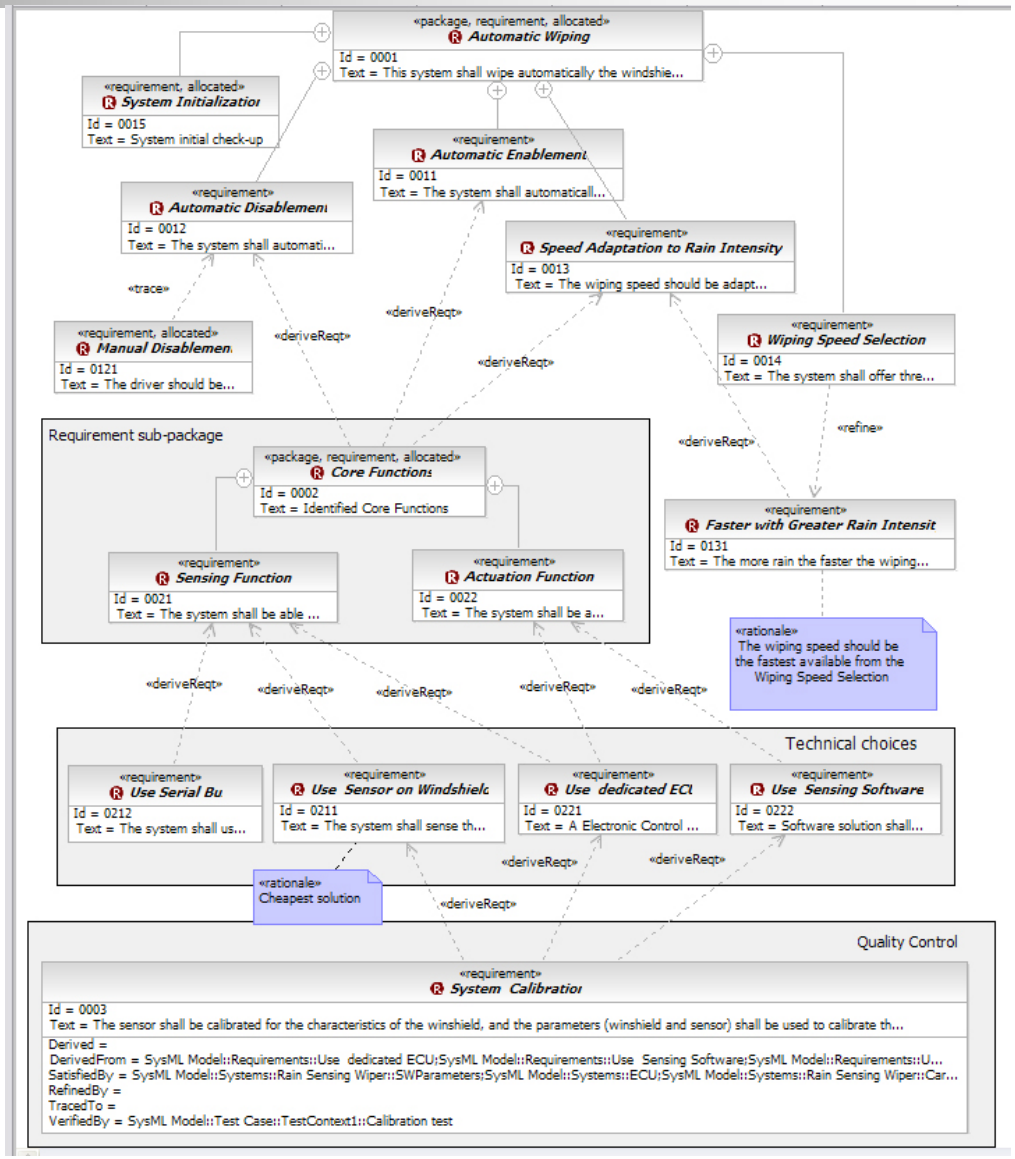


Figure 9 Example of Requirement Diagram

SysML requirement verification

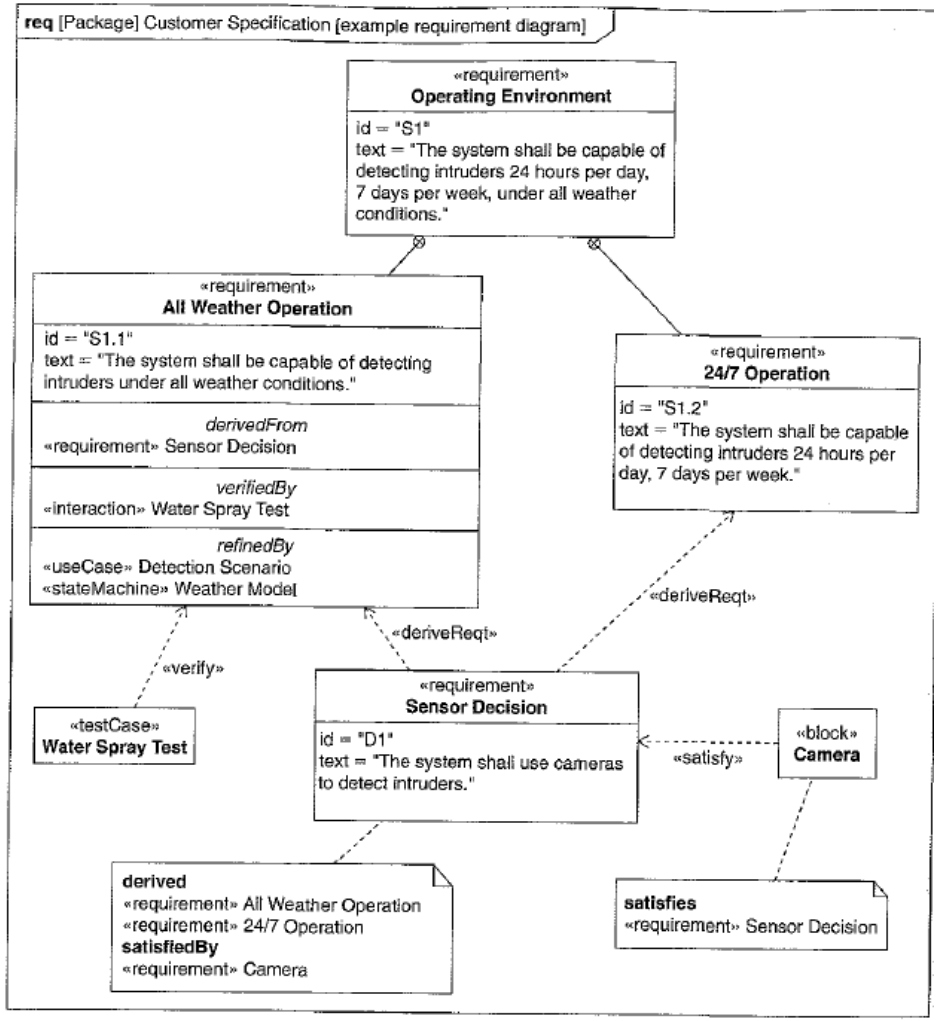


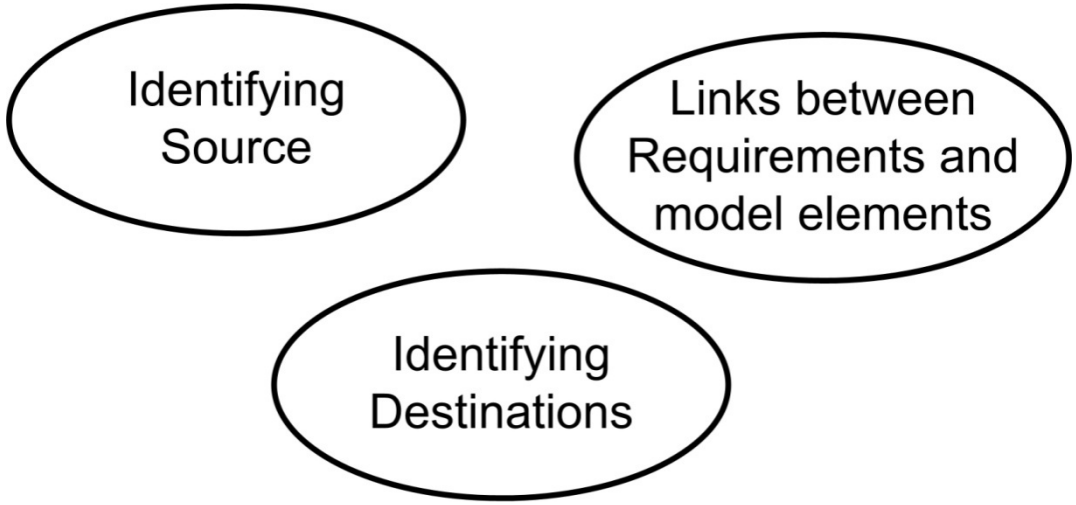
Figure 9 Example of Requirement Diagram

SysML requirement verification

Requirement tables

- Requirement traceability is defined as : " the ability to describe and follow the life of a requirement, in both a forward and backward direction, i.e., from it's origins, through its development and specification to its subsequent deployment and use, and through periods of ongoing refinement and iteration in any of these phases"

- Principle activities



Conclusion

- This presentation highlights the need of MBSE process for complex space robotic projects and presents a case study on SysML based SE process for MMS system of project INVERITAS.

- Systematic approach to modelling: transition from document centric to model centric using clear work flow

- Better for systems engineering compared to UML
  - ✓**Powerful than UML & Doors for requirement traceability.**
  - ✓**Capable of capturing the both structural and dynamic behaviour of the system**
  - ✓**Well defined hierarchy: Operational models, System models and Components models**
  - ✓**Risk reduction: Supports early and on-going verification & validation to reduce risk**

- Reasonably good compatibility for real-time simulation/execution

- SysML has an important drawback that the language is not formal and would require defining strict modeling guidelines to ensure streamlined model creation and organisation of complex projects.

- This paper contributes towards developing a standard modular package structure and guidelines.

References

1. This presentation highlights the need of MBSE process for complex space robotic projects and presents a case study on SysML based SE process for MMS system of project INVERITAS.

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Conclusion

Thank you